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PREFACE

Correlation and coördination of the enormous mass of facts already ascertained rather than addition to the already formidable array of undigested facts is the chief need of science at the present day. Especially is this true in the study of biology.

All plants and animals are manifestations of chemical reactions and physical forces intimately correlated with those of their environment of which they thus become an inseparable part. Some living things, both plants and animals, are very stable entities, able without change of form or essential change in their metabolism to meet a wide range of conditions and thus being found almost throughout the world. Others are very delicately adjusted, physically or chemically or both, to their surroundings reacting at once to even the slightest change and often capable of existence only within very narrow limits. Between these two extremes there is every type of intergrade.

We have been slow to recognize in this a striking similarity to a corresponding range in the chemical compounds found in nature. Some of these, like lawrencite, cannot maintain themselves on the earth in the present state. These correspond to such of the weeds as are not known to occur anywhere under natural conditions, or to such animals as camels only existing under domestication. Other compounds, like water and carbon dioxide, occur everywhere under all conditions.

Much has been written on the relation of biology to geography, but little attention has been paid to many points in the correlation of the two. Many features in the distribution and in the characteristic features of animals and plants are assumed to be inherent in organisms as living things quite apart from the inorganic world.

Since the bodies of living things are composed wholly of elements found in and derived from the soil it may be said that life sprang from the soil. The soil is a product of past and present alterations of the surface of the earth due to geologic and geographic changes. Chemical and physical phenomena affect all compounds and masses living or dead according to the same laws. Therefore there must be a much closer correlation between biology and geography than has hitherto been suspected.

In the present paper an attempt is made to draw attention to some phases in the relation of geography and biology which appear to be of special significance and interest.

INTRODUCTION

The Food Supply of Organisms.—In order properly to appreciate the relations of animals to geography their dependence on the changes in the exposed earth surfaces first must be considered.

On land the frosts of winter and the heat of summer and the intermittent action of the rain by its mere weight alone as well as by the power of fresh water of dissolving solid substances are continually wearing down the rocks. A portion of the products of this process form our soils and other portions are delivered to the sea in the form of muds and sands and of various substances in solution.

On the soils grow plants of all descriptions, sometimes in great abundance, forming huge forests and extensive grassy plains, sometimes in less abundance.

All the animals on the land are of course supported directly or indirectly by the plants, since only plants are able to form organic out of inorganic substances.

But there is a curious relationship between land plants and animals that is commonly overlooked. In order to grow a plant must have a relatively large amount of green leaf surface exposed to the action of the sun's rays. If this be reduced below a certain minimum the plants will die. At the same time most plants produce more leaf surface than they really need. In the delicate balance of nature the difference between the actual necessities of the plants in leaves (or corresponding structures) and the whole amount produced represents the food supply of the insects and plant feeding creatures generally, and the things that feed on them.

Nature is so adjusted that plant-feeding creatures, held in check by predators and parasites, never, under natural conditions, deprive the plants of more leaves than they can spare; and, curiously, certain plants when raised in the absence of their insect or other normal enemies grow better if their surplus leaves be cut away.

At the beginning of the winter or of the dry season the green leaves cease to function; they are of no further value to the plants. In most of our plants and in many in the tropics they wither and fall off.

The dying and falling of the leaves in autumn and at the beginning of the dry season, and more or less constantly at other times as well, means the accumulation of a vast reservoir of foodstuffs for anything capable of making use of it.

Bacteria and fungi thrive on this detritus, and earth-worms, many kinds of snails and insects, as well as other creatures, feed either on this decaying vegetation, or on the bacteria or fungi in it, or on the living things that feed on them.

Much of the material is consumed where it lies upon the ground, but a vast amount is washed into the rivers, especially by the floods of spring and at the breaking of the rains, and goes into the sea. Much of this is still in a condition to be eaten by detritus-feeding animals; much more, especially in the form of organic substances in suspension or solution, is available as food for the marine plants.

Our knowledge of the origin of the substances on which the plants and animals of the sea depend for their existence is very vague indeed. But the evidence seems to indicate that for the most part life in the oceans is dependent on foods brought down from the exposed land areas. In the first place, sea life becomes scarcer with increasing distance from the land and toward the middle of the oceans, especially in the Southern Hemisphere, almost completely disappears. In the second place, sea animals are largest and most abundant on those shores which have a copious rainfall, especially on rugged and on cold coasts where it may be assumed that material from the land would reach the sea unaltered in the greatest quantity, and would remain unaltered for the longest time.

Plants and Animals Defined.—Before it is possible profitably to discuss the interrelationships of animals and plants with their surroundings or environment it is necessary to define them in terms of their environment.

Animals and plants are composed entirely of elements found also in inorganic substances and compounds. But in the bodies of the animals and plants these elements are combined in the form of living substance or the products of living substance.

Just what life is we do not know. But as living substance is composed of the same elements as those that make up inorganic substances we may consider life as the ability to increase in bulk indefinitely in such a way and in such varied forms as shall enable the increase to take place to the best advantage.

Primarily each animal or plant is an intricate complex of coördinated and interrelated chemical reactions continually taking place within a body so adjusted to the physical forces by which it is surrounded as to enable these chemical reactions to be carried on to the best advantage.

These chemical reactions require a constant supply of new materials to replace substances broken up or recombined into unusable forms. They take place in a liquid medium, the liquid being water. In some of these reactions oxygen is a necessary factor.

In other words animals and plants require a constant supply of foodstuffs, of water, and of oxygen; and conversely wherever there is an adequate supply of these three essentials there animal and plant life will be found.

ENVIRONMENTAL CONDITIONING FACTORS

Food Substances and Water.—The chief factor affecting organisms is the immense diversity in the form in which the necessary supply of new materials is offered.

Only the plants containing chlorophyll are able to synthesize inorganic into organic substances. As they can do this only with the aid of sunlight the world's organic life is entirely supported by plants growing on the surface of the exposed land areas, or attached to the bottom, freely floating, or suspended in water of not more than six hundred feet in depth.

These plants get the materials necessary for their growth from substances dissolved in water and from gases in the air or dissolved in water.

All of the animals and the other types of plants get the substances necessary for their growth directly from any one or more of the various parts of the chlorophyll bearing plants, or from their dead and more or less decomposed remains, or from such animals or plants as feed upon the living or the dead substance of these plants, or from the carnivorous or parasitic animals or plants that feed on them. To illustrate the fact that wherever there is a reservoir of food, permanent or temporary, capable of supporting life there life of some sort will be found, those insects may be mentioned that feed on the dead remains of insects caught in the pitchers of the carnivorous pitcher plants or by the tentacles of the carnivorous sun-dews, on the exudations of other insects, as certain moths on the large fulgorids, on the spines of some of the larger caterpillars, on hairs, feathers, or other epidermal structures, or on excrement.

Since foodstuffs are available for use by animals and plants only when accompanied by an adequate supply of water, the very unequal distribution of this essential substance is the chief controlling factor affecting all life on land. Some regions are extremely wet, others are

extremely dry; in others the supply of water is very variable at different seasons of the year, or the humidity may vary greatly between the night and day. In the north and south for a greater or lesser portion of the year the water becomes ice, in other words it changes over into a form in which it is not available for use by the very great majority of plants and animals.

Thus every living thing on land, whether plant or animal, must have some provision to counteract the variability in the available supply of water, and especially to guard against the loss of moisture.

For instance all the adult insects, like house-flies and June-bugs, wasps and butterflies, are protected by a tough impervious covering. Among the vertebrates the reptiles and birds are the best protected against the loss of moisture; consequently reptiles and birds, with a few insects having an insatiable thirst for nectar, sap or blood, are the characteristic creatures of hot and extremely arid regions in the day-time. In the cool and relatively damp nights in the same regions mammals take the place of reptiles. With increase in humidity mammals become abundant and amphibians (toads) appear.

The young of house-flies, which live in moist decaying substances, and the young of June-bugs, which live in moist soil and are commonly called "white-grubs," are soft and flabby more or less like earth-worms. So are the young of wasps, all of which live in cells carefully prepared to guard against a loss of moisture. Compared with these, those caterpillars which are the young of butterflies have a thick tough skin; and of course they take in water all the time with the portions of the leaves they eat. Many of them, like the caterpillars of the fritillaries, conserve their moisture by feeding only in the night time, in the day hiding beneath sticks and stones. In the caterpillars of those butterflies that feed on ants, living in the ant nests below the surface of the ground the skin is very thin, and they look much more like the grubs of beetles than they do like the young of butterflies.

Much as the soft and thin skinned young of house-flies and of June-bugs differ from their parents, so the marsh-living and aquatic frogs and salamanders differ from the toads.

It is the same with plants as with the animals. All land plants have some special adaptation to prevent danger through their drying up. In many cases plants flourish in the rainy season, and when that passes go into a drought-resisting stage or go to seed, and the seeds live over on

or in the ground until the rainy season comes again. Very many insects do about the same, that is, they live their active lives in the wet season and spend the dry season in a resting stage, usually the pupa, buried in the ground or in some other situation where they will not lose their moisture.

TEMPERATURE.—Both on the land and in the sea temperature is commonly regarded as an important factor in controlling life. It seems to be not so important of itself as in its indirect relation to organic life. On land changes in temperature, seasonal or diurnal or irregular, profoundly affect the humidity of the atmosphere, and the latter profoundly affects all the organic life. In other words, changing temperatures on land affect the plants and animals mainly by the disturbances they cause in the vital problem of securing and conserving water.

So far as plants and animals are concerned, one of the most important things concerning water is that at low temperatures it suddenly changes into ice; that is, it passes over into a form in which it can no longer be used by them. In the winter when the ground and ponds are frozen the plants cease to grow and become dormant. The turtles, snakes, lizards, and frogs; the butterflies, bees, ants, and other insects; the snails, and earth-worms, all pass into the long sleep known as hibernation. All birds are warm blooded and are perpetually active, and all that cannot find sufficient food fly south; but some mammals, like the bears and certain, but not all, the mice, sleep like the insects, while some others, like the northern squirrels, sleep most of the time but appear at intervals on warm and sunny days.

On land the activity of most living things comes to an end at a temperature of about 40°, or at the lowest at the freezing point of water, a substance which is essential for the carrying on of the life processes but which few living things can use in the form of ice because of the great expenditure of energy necessary to convert it into the liquid form.

When the winter comes the plants and animals, with the few exceptions noted, pass into a resting stage in a way quite comparable to the way in which the tropical plants and animals pass the dry hot season. In some places in the tropics at the end of the wet season the trees for the most part shed their leaves and the insects disappear. A photograph of such a region much resembles one of a snowless day in winter in this latitude. Conditions are the opposite in that in one case nature is sleeping from the effect of excessive heat and in the other from the effect

of excessive cold, but the same in that in both cases the plants and animals are sleeping over a period in which they cannot get sufficient water.

Some creatures are so versatile that they are able in the same way to pass over both hot and dry and cold and frozen seasons. Thus the handsome northern butterfly known as the tortoise-shell (*Hamadryas j-album*) lives through the winter as a perfect butterfly in a torpid state in protected situations. In hot dry spells in summer you will sometimes find it hidden away in barns or other places in the same torpid state as that in which it spends the winter.

When the weather gets extremely cold it also gets extremely dry and, speaking generally, dryness is more dangerous to life than cold. This raises an interesting question. Why do the small birds that visit us every winter from the north, such as the horned larks, snowflakes, kinglets, creepers, and others, leave their summer homes? Is it not probable that they are induced to visit warmer regions not so much on account of the cold itself as because of the dryness which accompanies the cold? For most of these there is quite as much food available in winter in their northern homes as there is with us, but the water content of that food is considerably less. It is noticeable that with us these little birds keep mainly in damp localities, in low damp woodlands, about ponds and streams, or near the sea coast.

Temperature affects directly only such animals and plants as are so very delicately balanced as to require a fixed and usually high degree of heat for the maintenance of their internal chemical reactions. In this category fall the most active vertebrates, the mammals, birds, and reptiles. In the mammals and birds the body is insulated from the temperature changes in the air about them by a layer of air which is held in place by a covering of hair or feathers, or by a thick covering of fat. Their body temperature is high and constant, and quite independent of the outside temperature. Reptiles require a relatively high temperature, but have no mechanism for controlling it. Therefore all of the active types are tropical or subtropical, only the least active, the turtles and snakes, occurring in the colder regions. The amphibians are all inactive, and the toads, frogs and salamanders extend far into the colder regions.

Among the other forms of life temperature seems to have the most effect on bacteria and protozoans, many of which will thrive only within curiously narrow limits, and most of which require a considerable degree

of heat. Both of these features are characteristic of the reproductive cells of all the other animals, which in their temperature relations as in their structure are more like the protozoans than they are like the animals from which they are derived.

In the sea changes in temperature are accompanied by a corresponding alteration in the gas content of the water, and it is this rather than the degree of heat or cold that chiefly affects sea life.

LIGHT.—Light has long been recognized as an essential for the growth of every chlorophyll bearing organism, and from the most recent work it would appear that it is also necessary, though in much less intensity, and in somewhat different quality, for most, if not indeed all, other organisms.

It may well be doubted whether any organism lives in complete darkness, excepting perhaps for certain parasites. Those inhabiting deep subterranean streams appear to do so, but the subject has never been thoroughly investigated. They certainly seem to live in a minimum of light.

In the deeper portions of the sea there is no light, or at least no effective light. But sea creatures, especially those remaining always beneath the illuminated surface layer of water, are remarkable for the luminescence developed in all types save for a few that feed on luminescent organisms.

This general occurrence of luminescence among the creatures of the sea has never been satisfactorily explained. It is not known to occur in any of the animals of fresh water excepting in the aquatic young of certain fire-flies. But the few animal inhabitants of the deeper parts of lakes have never been studied from this viewpoint.

Luminescence certainly would not be of such general occurrence in the sea were there not some outstanding reason for it common to all groups of animals. The only possible explanation is that luminescence fulfils some function of importance for the well being of every type of animal. In other words, the light emitted must be a chemical necessity.

The hypothesis that luminescence in sea creatures is a physiological necessity for those living beyond the reach of sunlight adequately explains the major features of its occurrence, such as its absence in shore living individuals of species which in deep water are brightly luminous.

The black color so general in the deep sea fishes, sometimes replaced by red, and also in certain other deep sea creatures, probably serves pri-

marily to retain within their bodies the light from the luminous things on which they feed. Were this black color correlated with the darkness we should expect to find it also in cave living creatures, which instead are colorless. The deep sea fishes are largely non-luminous; but as their food is almost wholly of luminous creatures they do not have to be.

While light is apparently essential for all animal life, an excess of light, especially of certain types of light, is distinctly harmful. Light, therefore, has a profound effect on all the animals that live on land or in other strongly illuminated regions.

In the first place all land living animals must have adequate protection against the possibility of harm from sunlight, especialy direct sunlight. This protection is afforded by the development of more or less abundant pigment or coloring matter in the outer body covering, or in hairs, feathers, plates, or other structures which are outgrowths from the skin. Thus all animals on land really exist in darkness more or less complete, for all is dim twilight within their outer body covering.

From its original function as a protection against an excess of sunlight, coloration has secondarily developed toward the end of making sunlight useful through the formation of endless varied and deceptive color patterns by which the eyes of enemies are more or less deceived.

Animals with bodies adequately protected against light find light extremely useful in enabling them to find their food or to avoid their enemies. This they do by means of eyes. Every creature living above ground and in the open possesses eyes which, though they vary in perfection, are always adequate for the needs of each. Even nocturnal creatures possess eyes, most of them good eyes, some extraordinary eyes, though a few eyes only serviceable in distinguishing night from day.

Eyes taken collectively serve three different purposes. They may, as with us, be organs of vision giving a continuous photographic record of the surroundings. This is the usual type of eye found in animals on land. They may simply be organs to record the varying intensity of illumination without a visual function. Or they may simply record the relative intensity of heat. In the last alternative they are usually represented by black spots more or less scattered over the surface of the body. In birds, however, and in some reptiles which have the body unusually well insulated from the surrounding air there is a special heat detector called the pecten within the visual eye.

Where visual eyes occur they usually are the chief factor in the con-

trol of the actions of the animal possessing them. This is especially the case with birds, most of which find their food and escape their enemies almost wholly through their eyesight. It is almost as true of us.

Most of the animals we see are animals with eyes, the actions of which are largely or mostly determined by their eyes. It is therefore difficult to appreciate the fact that taking animals as a whole visual eyes are confined to three out of the twenty-two major types (vertebrates, arthropods, and molluscs) and by no means occur in all the species in any of these three groups. Structurally eyes are a wholly minor feature, useful in certain cases but really unessential. Eyes and pigmentation, simple accompaniments to life in illuminated regions, more than any other features have hindered the true appraisal of the relations of the various types of animals to each other and of all to their environment.

Sound.—Among the peculiarities of air is that of transmitting sound waves. The existence of sound waves has an important bearing on the activities of all the active animals on the land. Through the development of auditory organs they are assisted in finding others of their kind, in avoiding enemies, and if predaceous in finding prey. The presence of auditory organs usually is accompanied by the ability to produce sound in one way or another, mostly by means of special organs, external or internal, or by such means as tapping wood or rustling leaves.

The occurrence of auditory structures and of sound production are natural accompaniments to active life in a medium in which sound waves are readily produced. Like eyes and pigmentation, they represent a simple response to physical environment resulting in the immense development of a wholly minor feature.

Sound waves also pass readily through water; but sound waves in water are quite a different thing from sound waves in the air and far less available for general use by animals, so that the response to them is far less obvious.

LIFE ADJUSTMENTS

Birds and Bats.—Among the animals as a whole the most perfect vision, combined with the most perfect hearing, is characteristic of the birds. No birds are blind, though blind forms occur in all the other vertebrates, and no birds are deaf. Smell, taste and touch, however, are only very feebly developed in the birds.

Birds might almost be described as wonderfully efficient organic

mechanisms controlled by light and sound waves, to which they react with a speed and an inflexible accuracy not seen in any other creatures. Birds scarcely think, as we understand the term.

The life-long power of flight, both by day and night, possessed by the majority of birds renders them more independent of their surroundings than any other creatures. If conditions change in one region, they can find another suitable for them. They are also able to spend different seasons in different regions. Thus tropical birds of many different types are enabled to breed far beyond the tropics when in the summer tropical conditions extend far into the temperate zones.

Geographically independent, birds have always been similarly geologically independent. Since the disappearance of the toothed birds of the Cretaceous the changes in the birds appear to have been only in minor details.

The extraordinary development of sight, hearing, and flight, and the correlated ability to detect and to escape from danger, together with the possession of a fixed and high body temperature and almost perfect bodily insulation, have made the birds as a group the most independent of the physical condition of their surroundings of any type of organisms.

This independence of their immediate surroundings is correlated with a certain dependence on physical conditions not affecting other organisms. Sight being all important for the birds, duration of daylight becomes an important factor in their lives. For some birds, particularly in the Southern Hemisphere, this probably has a bearing on their migrations, since a longer day means a greater proportion of the time when sight is an aid in securing food and in avoiding enemies.

Such migrations as those of the golden plover and of the Arctic tern, which annually pass from far northern to far southern regions and back again, might be largely explained by an endeavor always to keep in the longest possible day.

As aërial creatures the mammalian bats compete with birds. But bats, except apparently for the large fruit eating kinds, are guided mainly by their hearing and have, as compared with birds, deficient sight. The mammalian eye is of a type that cannot be adapted fully to meet the requirements of aërial life. But bats possess the senses of smell, taste, and touch. Bats are only able to compete with birds as nocturnal creatures, as in the light of day the superior sight of birds places the bats under an insuperable handicap.

In order to appraise the different forms of animal life at their true

value and in their true proportions it is necessary to discount the profound effect caused by the immense development in certain types of minor secondary features confined to a single group or to only a few groups in which they are not always universal in occurrence. Eyes, ears, and pigmentation are the most deceptive of these, but there are several others, as for instance, the tracheal system of the insects and the hydraulic or water vascular system of the echinoderms.

All the creatures possessing such exaggerated minor features, because of their relative independence of factors not connected with these features, as is illustrated by the practical absence of the senses of smell and touch in birds, occupy positions apparently curiously detached from the sum total of their physical surroundings and consequently difficult to appreciate in terms of their physical environment.

If such creatures happen to develop in such a way that they place their chief dependence on physical factors which are generally dominant, they will profit accordingly, and will remain dominant types so long as those conditions are maintained. But the more complete the dependence on, or in other words the more perfect the adjustment to, any limited range of factors, the more sensitive is the organism to any change.

When we have learned to appreciate in terms of physical constants the outstanding features of all of the various types of animals we shall be able to reconstruct the geologic past with much greater accuracy than can be done by purely geologic data.

Animal Life a Direct Response to Chemical and Physical Environment.—Since animals are composed of elements found also in inorganic substances, and life is the ability to increase in bulk indefinitely in such a way as shall enable the increase to take place to the best advantage, the development of animal types must be a direct response to the necessity of continually maintaining a perfect correlation between a condition of maximum efficiency in the internal chemical reactions, and a condition of maximum efficiency in providing new materials for the continuance of those reactions.

In other words the varying forms of animals are nothing more than the varying responses to the different physical and chemical conditions which each of the several types is called upon to meet.

An animal may from the very first be under the necessity of securing food. But most types of animals when young are for a varying length of time chemically independent of their surroundings through having been

provided by the mother with a supply of nutritive material, usually in the form of yolk. By consuming this they are enabled to develop in a way which otherwise would have been impossible. Many go still further, the young being both chemically and physically independent through being isolated from the outside world either in a tough shelled egg or in the body of the mother. Some for a varying period after birth are carefully cared for by their parents, a few even until the adult stage is reached. All animals with eyes which in their reactions are controlled largely or even chiefly by their sight are retained within the egg or under parental care until the eyes are fully functional.

These varying degrees of insulation from outside conditions serve vastly to increase the opportunities for the diversification of the animal form, while at the same time they tend seriously to obscure the true interrelationships of the animal types.

If animals are viewed as controlled by chemical and physical considerations, it is easy to make out in the complex of the numerous animal types a simple plan to which they all conform.

Regions of Maximum Density of Life.—There is a most important trinity of factors affecting life in general that is not sufficiently appreciated. Life will be most abundant where there is a maximum of water permanently in the liquid state, a maximum of air, and a maximum of food.

Thus on the land the optimum conditions for both plants and animals are in the moister regions of the tropics where the rains are not so heavy as to be destructive by the weight of water falling, and the temperature is high, but not too high, and constant.

But in the sea these factors find their most perfect balance in a region wholly different. For the colder water gets the greater the amount of air and other gases it will hold in solution, and the longer will the organic matter in suspension or lying on the bottom be preserved. Thus in the sea the optimum conditions for both plants and animals are in the coldest oceans, in the polar seas in the summer when the sun is at its highest, and in the cold currents flowing out from these.

Regions of Maximum Variety of Life.—The regions supporting the maximum density of life will not be the regions exhibiting the maximum variety of life.

As each kind of animal or plant is adapted to a more or less definite ecological range, those regions will show the greatest variety of types which will present the greatest variety of conditions.

Since the bottom of the sea is everywhere at a temperature near the freezing point, and high mountains rise to above the snow line, it is evident that both on land and in the sea the maximum diversity in conditions is to be found in the regions where the sea coast is the warmest, that is, within the tropics.

The maximum variety of life, therefore, is in the tropical regions, on land at slight altitudes in rough and diversified land with an adequate rainfall, and in the sea at moderate depths, in both cases avoiding the maximum of heat and sunlight.

Region of Maximum Amount of Life.—The region supporting the greatest amount of life is naturally the region producing the greatest amount of foodstuffs, which is the region showing the maximum chemical activity. On land this is the region between about 30° and 60° north latitude where there is the greatest area of exposed land under conditions of rapid chemical and physical disintegration. In the sea the region supporting the greatest amount of life is the Arctic, the north Atlantic and the north Pacific, that is, the sea areas receiving the drainage from these same land areas.

The Geometrical Development of Animals.—All animals begin as a single cell. Some remain all their lives as single cells, while in others the original single cell becomes a more or less complex mass of cells.

Assuming that the earliest animals, like those of the present day, began life as a single cell, there are three alternative paths which subsequent development might follow. There is no reason for believing that these three paths were not followed simultaneously, that is, that animal life did not from the first develop in three divergent ways.

A single cell cannot increase in size beyond a certain point without serious interference with the chemical and physical interchanges on which life depends. On reaching the maximum size permitted by the chemical and physical restrictions, the animal cell divides into two; later these two each divide, becoming four, these four become eight, these eight sixteen, these sixteen thirty-two, and so on indefinitely.

In this process of division there are three paths that may be followed. As they divide the cells may separate from each other so that the individual animals always remain composed of a single cell. In other words on the division into two of the original cell each half may separate from the other becoming a separate animal half the size of the original. Further division would give rise to a corresponding number of entirely

separate animals, all when they reached the maximum size increasing by simple division into two. The so-called single celled animals illustrate this process.

But after division into two the cells might remain in contact and this contact might be maintained through successive cell divisions. Here there are two alternatives. The cells may adhere more or less irregularly so that a poorly differentiated mass of cells results, the mass as a whole being more or less distinctly radial in symmetry. The result of such development is represented by the sponges. But on the other hand cell division may take place by regular geometrical progression, the original cell dividing into two, four, eight, sixteen, thirty-two, and so on until a hollow ball of cells (a blastula) is formed which, by collapsing, would form a two layered cup (a gastrula) with the axis passing through the center of the opening and of the opposite pole, and the walls the same in all the radii. If such an animal form should continue its development to the adult stage, following to its logical conclusion the preceding line of geometric development, the result would be an animal radially symmetrical and composed of two layers of cells. Such an animal type is represented by the hydra and allied creatures.

We know that all animals begin life as a single cell which divides into two, and these derivatives continue to divide in the same way. Undoubtedly the original animals had a similar life history. But there is no logic in the assumption that the earliest animals were single-celled creatures of the protozoan type. It is far more likely that at the very first the dividing cells would take each of the three courses outlined, complete separation, formation of an irregular mass, or formation of a geometrical body developing into a two-layered creature with radial symmetry.

While it is most reasonable to suppose that all three alternatives were realized from the start, if any of the three were to precede the others it would presumably be the development of a more or less formless sponge-like mass from which on the one hand single celled creatures were derived, and on the other the geometrical multicellular types.

As typical of the single celled animals let us take the amœba as the best known. As typical of the animals developing into a formless mass we may take the sponges. And as typical of the result of geometrical cell division we may take the hydra.

The amœba, the sponges and the hydra are all radially symmetrical. The amœba is composed of a single cell; when it has reached the limit

of its growth from the economic viewpoint it divides in two. The sponges, with their systems of canals which penetrate the mass, are capable of indefinite growth without transgressing economic boundaries.

But with the hydra it is different. The hydra, or any creature similarly formed, must remain of a size suitable for the capture of its prey. There are four ways by which this may be done without interrupting a continuous increase in bulk. The animal may do as the single celled amœba does, divide into two, or even into more, by the formation of buds which separate off and grow into complete animals. This occurs in hydra, in the sea-anemones, and in the solitary corals. It may do as the sponges do and grow into a large more or less radially symmetrical mass with the food collecting mechanism distributed over the surface, as in the case of the brain corals. It may form a bud which develops into another individual that remains attached to the first, the second individual may similarly produce a third, and the third a fourth, and so on, until a more or less geometrical plant-like structure results, bearing many individuals or polyps, as in the case of the stag-horn corals, red corals, sea-pens, sea-fans, and similar things.

There is still another alternative. The single celled animals, or protozoans, as we know them now, are mostly asymmetrical with a more or less definite anterior end. In the same fashion a multicellular animal may start to develop in radially symmetrical fashion, but during the course of its development lose the radial symmetry and become bilaterally symmetrical with an anterior or head end toward which naturally the mouth and the chief sense organs converge, and at which the controlling nerve centers become assembled. With a bilaterally symmetrical more or less elongated form and a head end at which are the controlling nervous centers, the sense organs, and the mouth, and endowed with locomotion, an animal becomes independent of its immediate surroundings. It is able to search for food and thus to get sufficient nutriment to enable it to grow to almost any size.

But what evidence is there that the bilaterally symmetrical animals have any connection with radially symmetrical types? The gastrula or two layered cup or its equivalent is found in all animals excepting those composed of a single cell, the protozoans, and those composed of an unorganized mass of cells, the sponges. The latter are singularly diversified in their early stages, but these never include a gastrula comparable to that in the other multicellular animals. The gastrula is the pre-adult stage in the hydra, the sea-anemones, the corals, the sea-pens,

and their allies. In all other animal types it is the stage at which divergence takes place in all directions. In the flatworms and in the roundworms the adults show a bilateral symmetry with much of the original radial symmetry still remaining, but in all the other forms of animal life all traces of radial symmetry are lost.

All animals arise from a single cell; therefore we say that the single cell is the fundamental feature of the structure of all animals. But if this is true, then it is equally true that the gastrula, or the radially symmetrical element, is the fundamental feature of the structure of all the bilaterally symmetrical animals.

Especially to be remarked in the strictly bilateral animals is the constant recurrence of features characteristic of the radially symmetrical forms, such as the formation of plant-like colonies, as in the polyzoans, and reproduction by budding or division as in some starfishes and ophiurans and in many other types.

The constant recurrence of these features may mean either of two things. There may be a natural tendency in every animal group to adopt independently a colonial habit after the manner of the radially symmetrical types; or the constant appearance of these features may be due to an inherent principle common to all animals and inherited from a common origin in which these features dominated.

Generally speaking the tendency for animal types to form colonies or to reproduce by budding is inversely proportionate to its activity; that is, the more active the animal type the less tendency there is to produce colonies or buds.

Among the crustaceans there is only a single type that may properly be considered as colonial (*Thompsonia*), while relatively few reproduce by division in the early stages; all of these are sedentary forms. Among the insects a few types exhibit the phenomenon known as polyembryony —the formation of two or more larvæ from a single egg—but quite a number, as ants, bees, wasps, and termites, the last named radically different from the others and related to the cockroaches, form colonies which, although the individual members are all separate, show unmistakable resemblances to cœlenterate and other colonies. In the vertebrates these phenomena have almost completely disappeared. The remarkable powers of reparation possessed by certain amphibians are possibly a remnant of reproduction by budding, while the ceratioid fishes with the diminutive males parasitic on the females might be considered as colonial in habit though beginning as two or more individuals.

In true colonial animals the entire colony may form a unit and this unit may acquire locomotor powers as if it were a single animal. Examples of this are the colonial jelly-fishes known as siphonophores of which the Portuguese man-of-war is an illustration, natatory colonies of tunicates (*Pyrosoma*), and ambulatory colonies of polyzoans (*Cristatella*.)

True radial symmetry is relatively rare. Most of the protozoans are more or less asymmetrical, and most of the cœlenterates also are to a greater or lesser degree asymmetrical.

A tendency toward radial symmetry, more or less marked, occurs sporadically throughout the groups of animals which are primarily bilaterally symmetrical. Thus the adult echinoderms are usually more or less perfectly radially symmetrical, although when young all echinoderms are bilaterally symmetrical.

Animal Perfection Relative, Not Absolute.—One of the stumbling blocks in the study of zoölogy has always been the assumption that the most perfected animal type is necessarily that most like the human body in structure, that is, the vertebrate, while the least perfected are those least like the human.

But the criterion of animal perfection is relative, not absolute. It lies not in the gross anatomy of an animal, but in the balance between its physical and chemical body complex and the physics and chemistry of its environment. Just as there is no logical reason for supposing any one of the major types of animals to be necessarily older than any other, practically all of them, including the vertebrate, appearing in the Cambrian, so also there is no logical reason for assuming that any given animal type is more perfected than any other.

Each animal type is best fitted to meet the range of conditions under which it lives. As that is the only standard of perfection that can be maintained, we may safely say that all the animals living today are of the same relative standard of perfection. They all have the same length of developmental history behind them, and there is no reason to suppose that they have not all profited equally by it, although in different ways.

This is the only way of contemplating the development of the various animal types which in the first place allocates all the facts gained from a study of the embryology and morphology of the animals themselves in a definite plan, and in the second place brings a definite plan of animal development into harmony with the physical and chemical requirements.

In this view of animal development no time element is involved. The appearance of all the major types of animal life from the protozoans to the vertebrates may well have been simultaneous.

Place of Origin of Life.—In speculating on the region where the first life appeared several requisites must be kept in mind. In the first place it must have been a region with an adequate and constant supply of water. In the second place it must have been a region furnishing all the necessary elements in the relative proportions and in the form most nearly similar to those found in organic matter. In the third place it must have been a region of suitable and relatively constant temperature. In the fourth place it must have been a quiet region.

These conditions are not met with in water, either fresh or saline in any conceivable combination of salts or in any conceivable concentration. They are to be found only in saturated soils. The inference, therefore, is that life originated in the soils of swamps spreading thence into the water and at the same time out over the surface of the earth.

At the present time the maximum diversity in both plant and animal life is to be found in fresh water marshes, in the soil, in the water, and on the moist earth.

Of the twenty-two major groups of animals thirteen occur in fresh water marshes, while the remaining nine (priapulids, sipunculids, phoronids, brachiopods, chætognaths, echinoderms, pterobranchiates, balanoglossids, and tunicates) are all small groups including highly specialized types adapted each to a very limited range of marine conditions. But there is no evidence to prove that any of these types is primarily marine. The three known as fossils (brachiopods, chætognaths and echinoderms) are in the Cambrian rocks found together with animals (phyllopod crustaceans) now exclusively non-marine. All that we can say in regard to them is that they are adapted to conditions found locally in large bodies of water either fresh or saline, but at the present time found only in the sea.

Sea and Land Animals Compared.—The sea has commonly been regarded as the place of origin of all animal life. But there is no real evidence that this is true. The reason for the supposition is to be found in the greater diversity of sea animals as contrasted with the animals on land and in fresh water.

Just as for many years we have commonly looked upon the sea as the place of the origin of life, so also have we regarded it as the region

where the primitive germs of life by an evolutionary process expanded into the forms we know today. But very much of what biologists consider as the result of the evolution of the animal form is really nothing more than the necessary response to the physical restrictions of environment.

If you take the various forms of animal life and subtract from each those structural peculiarities which are immediately due to these physical restrictions imposed by their environment, you will see at once that the whole subject of the interrelationships of the major animal types take on an entirely new aspect.

Heretofore we have been led astray in our contemplation of sea life by the interesting fact that about three times as many of the more important types of animals live in the sea as are found upon the land. Indeed of the major types of animals nearly half again as many as all land living types together are exclusively marine.

This great variety in the form and structure of sea animals obscures another interesting fact. About three-fourths of all known kinds of animals live on the land and only one-fourth in the sea.

The reason for these curious contrasts is not far to seek. All land living animals have one thing in common. They must seek their food, for it will not come to them. Therefore land animals are almost wholly of those types, arthropods and vertebrates, which are best adapted for locomotion, with representatives of some others of fair locomotor powers, like the mollusks and the earthworms.

In the sea food substances when present not only lie upon the bottom, but they float everywhere suspended in the water drifting back and forth up and down. While useful, powers of locomotion are not essential for the creatures of the sea, for if they cannot seek their food it will be brought to them.

On land all creatures have to seek their food, but in the sea the food relations of the animals are of three kinds instead of one. Some, like the crabs, go after it as do the animals on land; some, like the corals, attach themselves to firm supports or, like the clams, burrow in the mud and let the water do the work of bringing food to them; and some, like jelly-fishes, simply float about suspended in their food supply.

Three possible ways of securing food instead of one means a corresponding diversity in the fundamental structure of the animals involved. But the relative uniformity of conditions in the sea, especially in regard to the most essential substance, water, permits the existence of the

numerous major types with relatively slight subdivision in startling contrast to what we find on land where infinite variation in conditions has resulted in infinite variation in those few major types fitted to meet the exigencies of terrestrial existence.

Correspondence Between the Marine and Terrestrial Faunas. —Just as on land the insects are the chief intermediates through whose services plant substance is made available for consumption by spiders, scorpions, predaceous insects, and most of the amphibians, reptiles, birds and mammals, and fresh water fishes, that are not plant feeders, so in the sea their close relatives the crustaceans are the main factors in the conversion of the substance of the marine plants into a form in which it may be utilized by other invertebrates, and by the fishes, whales, and seals.

While on the land the vegetarian insects are the most important creatures as intermediates between the plants and animals, land plants are so large that they may be eaten directly by even the largest types of creatures, as the great hoofed animals and the elephants. For this reason we are prone to overlook the importance of the insects as the intermediate food for larger animals. In the sea few things are able to feed directly on the small pelagic plants, so that here the insects' marine representatives, the crustaceans, are all-important.

In the sea the mollusks, especially the bivalved mollusks, are important intermediates; on land the land snails and fresh water mollusks are next in importance to the insects.

Both on the land and in the sea plant life is attacked by bacteria, various protozoans, and certain parasitic plants.

In the sea as on the land the largest creatures are the mammals, both in their average and in their maximum size. While on land the largest mammals are herbivorous types (elephants, cattle, etc.) in the sea the herbivorous types (manatees and dugongs), while large, are exceeded in size by some of the carnivorous (whales).

On land the most important of the parasites are insects, chiefly certain types of flies and wasps, with some beetles and a few moths. They are very largely parasites on other insects. In the sea the most important of the parasites are the crustaceans, of several different groups, especially isopods, copepods, barnacles and crabs. They are very largely parasites on other crustaceans. Both among the insects and crustaceans there are many parasites of parasites.

The tape-worms, spiny-headed worms, and nematodes so common as

parasites in animals on land are equally important as parasites in creatures in the sea.

VERTEBRATES PRIMARILY MARSH LIVERS.—In the consideration of life as a phenomenon which first appeared in marshes spreading thence into the open water and emerging on dry land it is necessary to explain the occurrence of the vertebrates.

It is commonly assumed that the first vertebrates were fishes which gave rise to amphibians, and these to reptiles, birds and mammals. Fishes are divided into three groups which have very little in common save for the fish-like form. First there are the cyclostomes (lampreys and hag-fishes), second the group including the sharks and rays, chimæras, ganoids, and lung-fishes, and third the bony fishes. *Amphioxus* and its allies, commonly placed with the fishes, is much more nearly related to the ascidians or tunicates.

The early stages in the development of the cyclostomes are similar to the corresponding stages in the development of the amphibians, and the skull of the most generalized type found among the salamanders has in some respects advanced but little beyond that of the cyclostomes. In the more specialized salamanders there are numerous points of resemblance with the ganoids. The skull of the tadpole has much in common with that of the chimæras and of the lung-fishes, while the chondrocranium of the adult frog has many singular affinities with that of the sharks, and particularly with that of the skates or rays. The only vertebrates which have transitory external gills besides the amphibians are the sharks and skates, the lung-fishes, and perhaps some ganoids. The only fishes in which the cerebellum is rudimentary as in the amphibians are the cyclostomes and ganoids. The sharks, skates, ganoids and lung-fishes have a pylangium with valves disposed as in the amphibians. Functional lungs are found in the lung-fishes, and morphological lungs in some ganoids.

There is, therefore, a considerable morphological relationship between the amphibians and all of the types of fishes except the bony fishes—that is, the cyclostomes, and the sharks and skates, chimæras, ganoids, and lung-fishes. All of these fishes appear as fossils in the rocks long before the bony fishes.

Of these fishes the cyclostomes are, except for the hag-fishes, either inhabitants of fresh water, or at least spawn in fresh water. The sharks and skates are mostly marine, but a few live in fresh water, while others ascend rivers for considerable distances. The chimæras are all

marine, but all live in deep water. The lung-fishes all live in fresh water, in the rivers of South America, Africa, and Australia; while the sturgeons, confined to the temperate regions of the northern hemisphere, either live entirely in fresh water or at least spawn in fresh water, and the other ganoids are confined to the fresh waters of North America and Africa.

The structural relationships between these fishes and the amphibians are therefore reflected in their habitats, for most of them, like all the amphibians, are creatures of fresh water. While the amphibians have tended toward a terrestrial existence, these related fishes have taken to large bodies of water, and a few of them to the sea.

The relationship between the amphibians and these types of fishes may be interpreted in either of two ways; amphibians may have arisen from the related fishes, or these fishes may be an aquatic derivative from amphibians.

Since the amphibians are of all the vertebrates the most diversified in structure and the only ones which in some forms are strictly aquatic and in others strictly terrestrial, and furthermore since they occupy a central position from which radiate on the one hand the reptiles, birds and mammals and on the other the equally distinct cyclostomes, cartilaginous and bony fishes, it seems most logical to assume that the parent vertebrates were the marsh inhabiting amphibians from which the other types arose by adaptation to a terrestrial or to a purely aquatic existence, notwithstanding the earlier appearance of fishes as fossils in the rocks.

The presence of gill slits in the embryos of all the vertebrates has been taken as indicating their origin from fishes. This is offset, however, by the lungs of the lung-fishes and the ganoids which were the earliest of the fishes to appear. Besides, the presence of gills does not necessarily mean that their possessor lived in water, as witness the land crustaceans. In a saturated atmosphere gills would be more efficient than lungs, so that the embryonic gill slits of the vertebrates is by no means a certain indication that the prototypes of the present vertebrates lived in water, though they must have lived where there was no danger from desication.

Animal Variation.—The chemical and physical relationships of animals are of two kinds, internal and external. The young of all animals vary in all possible directions from their parents, and in all directions this variation runs to great extremes.

The limit of variation is determined by the ability to exist in the

variant form. Thus the variations in any given animal type which have been recorded are only that fraction of the entire range capable of existence under more or less the same conditions as those surrounding the parents, the more extreme dying at progressively earlier and earlier stages.

Extreme variants are usually classed as aberrations, abnormalities, or deformities. But in reality there are no such things in nature. Everything follows a definite plan, and that plan is always to be seen if we will take the trouble to look for it.

Thus among the vertebrates there are two well marked lines of deviation from the structural average both of which are characteristic of certain types and occur as deformities or abnormalities in others in which they are incompatible with other features necessary for existence.

In all the groups of vertebrates there is a marked tendency toward great enlargement of the hinder pair of limbs with a corresponding reduction in size of the anterior pair. This is characteristic of the frogs, dinosaurs, moas, ostriches and other birds, certain fishes, and such mammals as the kangaroos, rabbits and hares, jerboas and jumping mice, and others. It is a not infrequent " deformity " in cats and cattle, and probably in all other vertebrates. Enlargement of the fore limbs at the expense of the hinder pair is characteristic of such birds as goat-suckers, frigate-birds and others, of the pterodactyls, of flying and certain other types of fishes, and of bats, most monkeys, and certain other types of mammals.

Among the butterflies individuals occasionally are found which are male on one side and female on the other; sometimes the wings of a single individual are divided into irregular or more or less regular patches some of which show the male and the others the female coloration. Many cases of hermaphroditism are also known from other insects and from all the groups of vertebrates. Hermaphroditic individuals in bisexual forms are abnormal only when judged by the standard of their parents. Viewed in their broader aspect they are not abnormal but represent a recrudence of a tendency everywhere present among the animals to unite both sexes in single individuals. Such bisexualism is a characteristic feature of the individuals in a number of different types of animals, occurring occasionally in all other types where its fixation as a normal feature is not compatible with other economically necessary features.

Extreme variants range all the way from frequent to very rare. But every type of variant capable of existence seems to be recurrent in succeeding generations, and it has been found that some, at least, are strongly dominant when bred with the parent type.

The occurrence of many variants may be induced by unusual conditions surrounding the animal in the early stages, or to the influence of such conditions on the parents. An example of changes due to external factors is seen in the carnivorous butterfly *Feniseca tarquinius* of which individuals from a colony near Boston raised in the north had the black markings extended, while their brothers and sisters brought to Washington and raised in a heated house had the black markings much restricted. It is possible radically to alter the color scheme of many butterflies by raising them under more or less extreme conditions; but most of the alterations so produced have been also found in nature.

By far the greater number of known variants are due to purely internal factors; but a readjustment of these may give rise to a physiological instability which can only persist under a small range of conditions.

Some variants have a wide geographical range. Thus among the butterflies the common *Euphydryas phaëton* of the northern states occasionally gives rise to a curious form known as *superba,* while the southern representative of the same butterfly, *Euphydryas phaëton schausi,* living under conditions which are more or less different, has an identical aberration (*magnifica*).

Some variants seem to be localized, occurring only in a small portion of the specific range. Thus in the abundant and widely spread butterfly *Dryas cybele* a curious form with the venation absent from a portion of the wings and the color pattern correspondingly blurred (*D. c. bartschi*) is known only from a single bog in Roxbury, Mass., where several individuals have been secured, while another curious form (*D. c. baal*) is only known from the northern portion of the Middle West where a number of examples have been found. A corresponding form of another species (*Dryas aphrodite bakeri*) is only known from the same region, while this species possesses a curious variant (*D. a. hughi*) only known from a single bog in Essex, Mass.

An interesting case of a localized variant is seen on the West Indian island of Grenada where the local honey-creeper (*Cœreba*) is wholly black; but on the Grenadines, between Grenada and St. Vincent, which are faunally outliers of Grenada, only the normally colored form is

found. On the island of St. Vincent there lives a similar but slightly different honey-creeper. This now only occurs as a black form, the normally colored form not having been seen for many years.

It may be mentioned that on Grenada a South American hawk (*Regerhinus uncinatus*) is found which here always retains the juvenile plumage throughout life, while on St. Vincent there is another South American hawk (*Uribitinga anthracina*) which never acquires the fully adult plumage characteristic of the continental birds.

Other variants are localized not geographically in the generally accepted meaning of the term, but within a limited range of physical conditions. Thus *Cynthia cardui jacksoni,* in which the rounded spots on the hind wings are enlarged with conspicuous blue centers, is known from New England, California, Mongolia, France, etc., that is, from such places within the specific range as present comparable physical conditions.

A race characteristic of one geographical area may occur as a more or less frequent variant elsewhere. Thus from Utah to New Mexico there lives a form of *Dryas aphrodite* (*D. a. cypris*) which is light in color and has the fore wings long and the hind wings rather short. This would seem to be a form of powerful flight adapted to windy mountain regions. It occurs, however, as a rare variant at Essex, Mass. A dwarf form of *Dryas cybele* with curiously short wings (*D. c. carpenterii*) is found from New Mexico southward. This also is found in New England as a rare variant. In this connection it is interesting that those tropical butterflies that are found from Virginia northward here occur only in the extreme " wet " form, the so-called " dry " form being wholly absent.

In many butterflies the spring brood is of very small size, the summer brood being much larger and usually also of a darker color. The extreme is seen in *Papilio xuthus* of eastern Asia and Japan in which the sexual organs, as well as the size and color, differ in the two succeeding broods. In our common yellow swallowtail (*Papilio glaucus*) in the far north there is only a single brood and all the individuals are very small. Further south there are two broods, the second of larger individuals than the first. Still further south the individuals of all the broods are of the same size, and all are large.

In different regions offering more or less different conditions the majority of animal types appear in more or less different forms known as local races or subspecies. The range of these local races may be

fairly extensive or very restricted depending on the width of the ecological range of the type in any one locality. Each animal species exhibits this type of variation according to its special peculiarities. Thus in many species of birds there is a progressive decrease in size from north to south, while in the butterflies the reverse is usually the case.

In some cases it has happened that two quite distinct local races of different origin have come to occupy the same territory, each filtering in from a different region. Thus from New York to Cuba and Costa Rica there occurs the magnificent *Papilio cresphontes,* which is a northern form of the South American *P. thoas.* In Cuba together with *P. cresphontes* there lives *P. thoas oviedo,* a local form of *P. thoas,* while from Texas to Nicaragua *P. cresphontes* and *P. thoas autocles* live together.

Convergent variation is well illustrated by several of our native butterflies. This seems to be not a response to internal or external chemistry or physics as in the other cases mentioned, but instead a reflection of the chemistry and physics of the bodies of other creatures, particularly of their enemies. A species immune, or relatively immune, to the attacks of the usual enemies of butterflies serves as a model which is copied more or less exactly by various others not immune. In North America the model toward which most of the other types converge is the common Aristolochia swallowtail (*Papilio philenor*) which is found from Mexico to the northern border of the United States except in the central mountain region from Colorado northward and in central and northern New England.

The common yellow swallowtail (*Papilio glaucus*) ranges from the far north southward to the Gulf of Mexico east of the Rocky Mountains. In the north both sexes are alike in color, but where the range overlaps that of *Papilio philenor* some or all of the females are black in color more or less like the latter.

The common yellow swallowtail of the Old World (*Papilio machaon*) is found in northern North America (variety *aliaska*). In the mountains of the West it passes over into several forms which are yellow, or black, or highly variable; while in the coast region of California and in North America east of the Rocky Mountains, that is, everwhere within the range of *Papilio philenor,* all of the forms are black, the females more completely so than the males.

In northern North America there lives a common butterfly of a very

different type called the American white admiral (*Basilarchia arthemis*) which is black with a broad white band across each wing. White banded wings are a very characteristic feature of this group. Passing southward, in central New England, and further southward in the mountains, this butterfly passes over through a complete series of intergrading forms (*B. proserpina, B. albofasciata*) into a form (*B. astyanax*) with no trace at all of wing bands which ranges southward to the Gulf of Mexico. In other words, on entering the range of *Papilio philenor* this butterfly also assumes a type of coloration much more like the latter than like any of its relatives.

Where the range of a model is as broad as, or broader than, the range of the butterfly which copies it, instead of convergent variation we find mimicry. This occurs in eastern North America in the so-called viceroy (*Basilarchia archippus*) which, though closely related to *B. astyanax,* is colored like the common milk-weed butterfly (*Danaus menippe*). The spice-bush swallowtail (*Papilio troilus*), the range of which is included within the range of *Papilio philenor,* is probably another case.

Structural anomalies of any sort may become fixed as definite characters of species, genera or higher groups provided only they are compatible with the economic limitations. This occurs in the largest of the groups of butterflies (Nymphalidæ) in which the first pair of legs is deformed and useless, in many crustaceans which have more or less distorted bodies, and in many parasites. In nature any variation, or even deformity, no matter how grotesque, may become a normal feature of a special type provided only that the varietal or malformed individuals manage to reach a situation in which they can survive. We see this in domesticated animals, particularly dogs, and in various types of parasites which are so hopelessly defective that they are unable to exist except as parasites.

These few examples serve to show the major types of variation. Variation may arise from causes wholly within the animal itself, it may be induced by external inorganic factors, or it may be induced, or at least moulded, by the activities of other creatures, principally enemies or prey.

Animals vary all the way from those of a fixed type, almost always abruptly different from their allies, showing no appreciable variation, to others very variable, and some so very variable in their younger stages that less than half the young are capable of reaching the adult

stage under the conditions in which the parents live. Variation may be by a long series of almost imperceptible steps, or by wide and sudden jumps, or by both in the same form. In many cases one sex is constant, or practically so, but the other highly variable, or either or both sexes may be constant in one locality, but highly variable in another.

So far as we can see, in the earliest fossils new forms arose mostly through internal changes so that a genus might include many, or at least several, species in the same locality. This is still true in certain regions, particularly in the Caribbean Sea, in South America, in central Asia, and in New Guinea. But as a rule at the present day each species has its own specific chemical and physical limitations of environment.

In view of the abundance of variants of all degrees in all the forms of animal life at the present day, each form of variant being a potential new subspecies, species, genus, or unit of a higher order, it would seem that the formation of new animal types is going on at least as actively as at any epoch in the geologic past. The black honey-creeper on St. Vincent, for instance, seems to be a species which has originated and become dominant within very recent years. Were early records sufficiently detailed we probably would be able to determine many other similarly recent species.

One often hears it said that animal types increase in size, reach a maximum in size and extreme development of various features, and then suddenly disappear through type senility. But there is no evidence whatever of such a thing as type senility. The supposedly decadent elephant is composed of protoplasm which is certainly no older than that of the far from decadent mouse.

From a study of the normal variability of animals there is to be deduced a much more logical explanation of this phenomenon. Every animal type produces both dwarfs and giants in every generation. It may be that abundance of food and absence of competitors will favor the existence of the giants, in which eventuality the animal type will increase in size and also in specialization in other features. But increase in size means decrease in the number of individuals in the area inhabited. Decrease in the number of individuals means a corresponding decrease in the number of variants, and hence results in gradual fixation and stabilization of the type through reduction of the variants to a point where they become simply wholly isolated abnormalities. Once stabilized through reduction to a point where variants are

simply sporadic and wholly isolated individuals, an animal type becomes wholly dependent on the maintenance of conditions as they are, and any changes in these conditions results in its extinction.

The reason why animal types have persisted through succeeding geological ages in the smaller and more generalized forms is simply that in these there are always variants in sufficient numbers so that changing conditions may be met by the development of a suitable form from among these variants.

Expansion and Restriction of Animal Types.—On its first appearance every new form, provided it survives, at once spreads out to the limit of its possible adaptation to the environment. It may continue to maintain itself throughout an extensive area, or it may die out in such a way as to occupy a region far removed from the point of origin, or two or more widely separated regions one of which may or may not coincide more or less with its place of origin.

An animal type may be more or less inflexible with a small ecological range so that the remnants, though widely separated geographically, are morphologically very closely allied. Such is the case in the pierid butterflies of the genus *Baltia* which is represented by two species at high altitudes in central Asia and by another in the Andes. The allied genus *Eurymus* (*Colias*) inhabits both regions and all of the intervening region, in South America extending southward to Terra del Fuego. Extensive as is its range, *Eurymus* shows little diversity in its major features, and its present range suggests the origin, in the remote past, of the at present widely discontinuous distribution of the genus *Baltia*.

Another interesting type of distribution is illustrated by the genus *Gonepteryx*. This genus is most abundantly represented in central Asia, extending southward into northern India, westward into Europe and northern Africa, and eastward to Japan. In tropical America it reappears in the form of a very closely related genus (*Amynthia*) with two enormous species.

A further development of this same sort of distribution is seen in the fritillaries (*Dryas*) which in tropical America pass over through intermediates into a group of butterflies of a very different aspect, the heliconians, to which one of the oriental genera (*Cethosia*) is closely parallel, and in the morphos and brassolids of South America which are offshoots from the satyrids exactly corresponding to the superficially very similar but really very different amathusians of the tropics of the

Old World, which are connected with the satyrids through another line.

All possible intergrades are found between strict circumpolar distribution, circumpolar distribution extending southward to the tropics, and circumtropical distribution as illustrated by the trogons among the birds, or by the tapirs as between America and Asia, and by the elephants as between Asia and Africa. In general the difference between corresponding forms increases in proportion to the distance from the north pole, whether there be intergrading forms or not.

In the Southern Hemisphere there are several curious corresponding types which differ very widely from each other in the different regions. Thus in South America there are two groups of marsupials, one of which also occurs in southern North America. Elsewhere marsupials are found only in Australia where there are very many different types, none of which resemble the American. In the past, however, there was a type common to South America and Australia. The edentates are represented in Central and South America by the sloths, ant-eaters and armadillos, in Africa by the very different pangolins and aard-varks, and in the oriental tropics by a few pangolins. Except that both sorts are edentates, there is little correspondence between American and Old World forms.

These creatures simply carry further the present progressive discontinuity of animal types from north to south in the different regions of the world.

LIFE REGIONS

The Three Key Regions.—Having briefly sketched the more important features of animals and plants in their relations to environment, we may now approach the question of the place of origin of living things.

At the present time there are three regions of the world which are remarkable for possessing many closely related and more or less intergrading species and genera of animals and plants in many different groups, as well as many species and genera showing great variability, these endemic types being more or less abruptly different from anything found elsewhere.

This would seem to indicate that in these regions there is some factor or group of factors which operates to permit the existence and persistence of a wide range of variations, some amounting even to so-called aberrations, in many types, and through this to lead to the appearance

of new genera and species, some quite unique and others intergrading with other more usual forms. In other words, these three regions seem to be the chief centers of appearance and of dispersal of such new forms as are arising at the present day.

The largest and most important of these regions is that including the Himalayas and the mountain masses north and east. The next most important region is the Andean region in tropical and subtropical South America; this tapers northward into the Rocky Mountain region of western North America which at the present time is much less important. The third region is the island of New Guinea.

In the central Asiatic and Andean regions the land rises steeply from both wet and arid plains to above the frost line, and in the different portions of the multitudes of valleys an infinite diversity of environment is found which is reflected in an infinite diversity of the plants and animals. The same is also true in the island of New Guinea, except that no part of that island can be considered arid. But in the not distant past when it was united with Australia the conditions here were much the same as they are today in northern India and in western tropical South America.

The importance of these regions lies not only in the fact that here we find the maximum diversity of environment, but also in the equally important fact that they are regions of constant and continual change. They are the regions of maximum chemical and physical activity. In the hot, damp valleys chemical destruction of the rocks is proceeding at the maximum rate, while above the frost line the changing back and forth of water into ice and vice versa produces the maximum physical destruction. They are geologically restless regions with numerous earthquakes resulting in frequent and more or less extensive alterations of environment for a greater or lesser number of the endemic organisms in a greater or lesser portion of their range.

It is logical to suppose that in a continually changing region some plant or animal types would persist by maintaining the original form unchanged, others by passing to those variant forms which were best suited to meet the conditions of the moment. Among the latter the original form, however, would persist in any part of the habitat that remained unchanged, while different types of variants would be found in different places.

As variants are of all kinds ranging from minor and inconstant varieties through all possible intergrades to so-called aberrant "sports,"

in chemically, physically, and geologically active regions at the present time we presumably are witnessing the formation of new forms running all the way from minor varieties to distinct species and even genera, each one of which immediately on its appearance naturally will spread to the farthest limits of the territory within which life for it is possible.

New forms are of two kinds, those representing simply a physical and chemical readjustment to their new surroundings, and those representing an internal chemical and physical rearrangement with no direct relation to the environment other than inability to survive except under closely circumscribed conditions. As examples of the first I may mention the Japanese and the tropical house mice, both of which have been considered as distinct species although known to have been derived from the common house mouse, and as examples of the second I may mention the Japanese "waltzing mice" and the rhinoceros mice, both variants from the house mouse stock capable of existence only under domestication. Between these two kinds of new forms there are all possible intergrades.

The existence of these different types of variants would indicate that any animal type in a suitable but constantly changing region could give rise to a number of very different forms, several of which might live together in the same region, kept separate and apart by physiological differences which are not apparent correlated with their obvious external differences.

As examples of apparently quite recent forms which have arisen in New Guinea the paradise birds, which may be considered as glorified crows, are perhaps the best; among the butterflies there are the very numerous species and varieties of giant *Aristolochia Papilios,* the so-called ornithopteras, all, in the males as least, of gorgeous coloring. In South America there are the humming-birds, which are bizarre dwarf swifts, and among the butterflies the heliconians, the ithomiians, the Morphinæ and the Brassolinæ, while in the Riodinidæ we see an enormously developed group only sparsely represented elsewhere. In central Asia the genera *Parnassius* and *Eurymus* (*Colias*) among the butterflies and *Impatiens* and *Primula* among the plants are good examples.

Mountainous areas in general possess endemic forms in proportion to the diversity of the conditions in the region within the range of the respective types. Thus in the Rocky Mountain region, and especially in the Alps, we find an enormous development of forms of fritillaries

(*Dryas*) and certain other of the smaller butterflies, though a much less diversity of forms among the larger endemic animals.

Diversified regions must create their fauna and their flora from the available animals and plants; that is, from the animals and plants inhabiting the general area together with such casual immigrants as may come in from elsewhere. Some animals, unable to survive any change in their environment, will disappear with changed conditions; others, of a nature suited to meet the new conditions, will give rise to a multitude of forms more or less widely different both from each other and from the parent form. The same type of animal may be able to thrive under changing conditions in one region, though dying out in others. Thus in New Guinea the crows have blossomed out into a multitude of birds of paradise, while in South America the crow family (Corvidæ) is simply represented by four genera of jays.

The South American Region.—It is curious that the South American representatives of more or less cosmopolitan creatures are usually abruptly different from those elsewhere, while many types otherwise generally distributed do not occur in South America. Illustrations of peculiar types are humming-birds, toucans, curassows, screamers, and many other sorts of birds, two families of monkeys, forest dogs, brocket deer, and cavies and various other sorts of rodents. Among the types not here represented are the Insectivora, cattle, sheep, goats, and antelopes.

South America is especially remarkable for the development of flying creatures, birds, bats and insects. Among the birds it possesses far more distinct genera and species than any other region, and no less than twenty-four families of birds are peculiar to it. There are far more butterflies than in any other region, and the peculiar genera are in number nearly equal to those in all the rest of the world together. But there are no gliding mammals, nor are there any gliding reptiles. Among the mammals the prehensile tail is developed to an extent not seen elsewhere. Among the birds and insects, and to a certain extent in other forms, brilliancy of coloration is a dominant character, here being developed to an extreme seen in no other area.

On the assumption that South America derived its fauna chiefly from the north it is easy to account for most of the anomalies. The approach to South America is through a very rough and mountainous region, both in Central America and in northwestern South America, and also along the Antillean chain of islands. Such a region presumably

would act as a sort of strainer, preventing the passage of many creatures, and in certain types allowing only generalized forms to pass, barring the way to the more specialized and less adaptable. The relatively few forms reaching South America would find wide ecological possibilities, due to the absence of other types, and promptly would develop in all directions, by easy stages and by more or less sudden jumps, occupying all available situations. There is, however, another factor to be considered, and that is the micro-organisms and their carriers. How and to what extent these operate we do not know, but from certain indications they possibly play a considerable part in determining the facies of the fauna of South America.

The fauna of South America, therefore, is a part of the general fauna of the world which here is restricted to such types, for the most part generalized in character, as have been able to penetrate into the region and, once there, to become immune to the endemic diseases, and to local derivatives from those types.

Africa.—The fauna of Africa offers a curious contrast to that of South America. It is much poorer than the latter, and differs much less from that of Asia. Whereas South America is especially rich in birds, many of which are of peculiar character though mostly of generalized types, Africa is especially characterized by large and highly specialized mammals which include such creatures as gorillas, chimpanzees, hyænas, aard-wolves, aard-varks, giraffes, straight-lipped rhinoceros, hippopotamus, many kinds of antelopes, etc., found nowhere else, and numerous others, like pangolins, lions, leopards, elephants, gazelles and horses, represented also in other places. Africa has its share of endemic birds, reptiles, and other forms of life, but the number and diversity of its mammals is its outstanding feature.

The fauna of Africa is a fauna derived from Asia direct by way of broad avenues of approach offering no obstacles to immigration. A certain amount of selection has taken place, as such important types as deer and cattle are lacking, and there has been considerable modification of the intruding forms in response to local conditions. Micro-organisms probably are accountable for much of the selection that has taken place in the African fauna.

The Australian Region.—The Australian fauna, though very different, has most nearly the aspect of the South American. The mammals consist of a few monotremes, a vast variety of marsupials, and a few mice. The last two groups are represented in South America, but

by very different forms. There are a number of peculiar groups of birds, such as the paradise birds, the honey-suckers, cockatoos, lories, cassowaries and emus, and lyre-birds, while other groups, as the woodpeckers, trogons, and pheasants, are absent.

Generally speaking the birds and insects of the Australian region, like those of the South American, are remarkable for the brilliancy of their coloration.

Looking at the Australian region as a whole we see a singular geographical similarity between it and the South American. Entry from Asia is over a region, now an archipelago, which is everywhere mountainous, like Central America and the West Indies, but with this difference that the trend of the mountain masses is more or less across the line of ingress from Asia, not parallel with it as is the case with Central America and the Antillean chain.

At the present time the Australian region is isolated by the sea. But were the islands between it and the Malayan region to rise sufficiently to become connected it would be almost as effectively isolated by high mountains.

The mountains of New Guinea are (or were) to the Australian region in the production of new forms what the Andes are to South America, while most of Australia proper corresponds to the plains of South America.

The occurrence of monotremes, marsupials, and rodents only in the Australian region probably does not mean that they alone have reached the region. Of all the mammals the marsupials and the small rodents are probably the best adapted to meet adverse conditions. Both types are as a whole omnivorous; the marsupials carry their young with them, while the small rodents are exceptionally rapid and prolific breeders.

Viewed in the light of their early history it is not conceivable that the Insectivora, at least, could have failed to accompany the marsupials everywhere they went, and vice versa. But the Insectivora are and apparently always have been, singularly inflexible. All are small, all except the tree-shrews are strictly nocturnal, and all are carnivorous, and mostly insectivorous, with the possible exception of *Galeopithecus*. The various included groups mostly differ abruptly from each other, and there is a broad jump between the usual type and *Galeopithecus*, and a still broader jump between the terrestrial types and bats.

North America and Africa.—The fauna of Africa is simply an

extension of the fauna of Asia modified by local conditions the most conspicuous result of which is the preservation of many types which have died out in Asia and in Europe. In the main the fauna of North America is similarly the fauna of Asia, but here selection has been more rigid and more exacting and has taken a somewhat different line. With this more intensive weeding out various economic niches in North America have been occupied by the appearance of local types from a generalized stock. This is at the present time especially evident in the mountains of the West.

Both Africa and North America are curious in having a number of Asiatic types persisting only in regions far removed from Asia, these having died out elsewhere. In North America these types persist in the southeastern United States, in Africa in the region about the Gulf of Guinea.

One Asiatic butterfly (*Cynthia Indica*) occurs on the Canary Islands and on Madeira, though nowhere in Africa. On Madeira there is a North America species (*C. virginiensis*) found nowhere else in the Old World. The latter is probably a recent introduction, as it is picked up occasionally in Europe, but the former probably has persisted from earlier times.

South America, New Zealand, and Australia.—While the correspondence between the faunas of South America and Australia is largely due to similar insulation against the entry of creatures from the north, this does not wholly explain the facts. Many elements in the fauna (and flora) of southern South America, New Zealand, and Australia, particularly among the fresh water fishes and fresh water and terrestrial invertebrates, are so very similar, indeed in some cases actually identical, that there is no escape from the conclusion that these three regions were once parts of the same land area. This is also evidenced by the fossils, for instance by the occurrence in South America of large carnivorous marsupials of a type now occurring only in Tasmania, though in the past found also in Australia.

South America, Australia, and New Zealand are united by faunal elements absent from Asia, Europe, Africa, and North America. These are fewest in New Zealand, which has an exceedingly depauperate fauna, with no mammals except for two bats. But, as has often been pointed out, the fauna of New Zealand is not the fauna of a group of oceanic islands, for it includes such creatures as frogs and onychophores which in no conceivable way could have been transported over sea, and

also *Sphenodon,* a type of lizard once widely spread but now elsewhere extinct. New Zealand presents the last stages in the reduction of a continental fauna on a land mass long reduced to remote and isolated islands which have been subjected to profound geological changes. With the extinction of all the mammals and of all the larger reptiles flightless birds of numerous sorts and sizes have locally appeared to take their places.

Australia represents a similar condition, though less extreme. Here mammals are abundant and diversified, but of those types, marsupials and rodents, best fitted to persist in the face of extreme adversity, with the addition of a few monotremes. Additional marsupials occur in Tasmania representing types once occurring also in Australia.

In South America this fauna has been largely replaced by a fauna representing an infiltration from the Northern Hemisphere which for the most part has here assumed a local character and a curious endemic balance.

In the past there were in South America large numbers of curious creatures of large size more or less distantly related to types occurring in the Old World and in North America though of forms wholly peculiar to South America. But so far as we may learn from the fossil record, the interchange of animal types between North and South America has always been confined to forest or mountain living creatures and has never extended to large plains living types. In somewhat the same way the interchange of mammals between South America and Australia apparently has been confined to those types, the marsupials, which carry their young with them and are therefore most independent of locality.

In South America the rôle played by the flightless vegetarian birds in New Zealand and the vegetarian marsupials of large size in Australia and Tasmania was played by an equally incongruous assemblage of mammals of types other than marsupials.

Island Faunas.—The fauna and flora of mountainous islands is governed by the same principles that govern those of mountainous regions generally. But usually they seem to be, as in the Galápagos Islands and in the West Indies, of a much more distinctive character. The reason for this is that on an island immigration is impossible for many types, while changing conditions affecting the entire possible range of any given forms results in their extinction, permitting the occupation of their ecological range by offshoots, often more or less

bizarre, from other types. Island faunas, therefore, are made up of what seem to be more or less incongruous elements. Such things as giant flightless birds, elephant birds, moas, the solitaire, and the dodo; giant lizards, giant tortoises, or various sorts of mammals, may persist on islands long after they have disappeared elsewhere. They may even persist on widely separated islands (West Indies and Madagascar, the Galápagos Islands and Aldabra, etc.), giving a false impression of affinity.

Especially characteristic of the island faunas is sudden ecological expansion in various groups, but particularly in birds. Of all the vertebrates birds are the best fitted to escape from danger, either from predatory animals or from geological changes in a restricted area. On islands the amphibians are perhaps the first of the vertebrates to disappear, but if they persist they may become remarkably developed. Mammals rapidly become restricted with decreasing island size, and on the smaller islands are represented by some form of rodents, or are absent altogether.

The ecological range of the missing mammals is divided between the reptiles and the birds, being usually occupied by various flightless birds of different types and sizes ranging from flightless rails to giant pigeons (the dodo) and the giant moas.

This explains the chief peculiarities of isolated island faunas, which are the presence of large vegetarian reptiles, turtles or lizards, more rarely large carnivorous lizards, and large flightless vegetarian birds, together with an unusual development of local forms of birds in general.

Madagascar and the Mascarene Islands.—The Island of Madagascar and the Mascarene Islands possess a most peculiar fauna which naturally is most closely allied to that of Africa. But it lacks monkeys, large carnivores, all the large hoofed animals, elephants, rhinoceros, porcupines, squirrels, and other less conspicuous types. It is especially rich in lemurs and includes a peculiar family of insectivores, another of small carnivores, and several curious genera of mice. Many of the most characteristic of the African types of birds are lacking. The most interesting feature of this fauna is that it includes numerous types which have their closest relatives not in Africa, but in tropical Asia, South America, the Galápagos Islands, Cuba, and Haiti. The Asiatic elements might be explained by an assumed connection with Ceylon and southern India, but there is no such simple way of explaining the connection with South America. The fauna of this region must be

a part of the general world fauna which here has been restricted in such a way as to result in a certain correspondence with South America. One curious point of similarity with South America is that among the birds there are about a dozen genera which are of a generalized type and do not seem to fit into any of the major groups of birds as they are defined on the basis of the birds of other regions.

The West Indian islands represent a faunal stage of peculiar interest. The mammals are reduced to rodents, with insectivores (*Solenodon*) on Cuba and Haiti, and fossil sloths in the greater Antilles.

SUMMARY

All plants and animals are manifestations of chemical reactions and physical forces intimately correlated with those of their environment of which they thus become an inseparable part. Chemical and physical phenomena affect all compounds and masses according to the same laws; hence there must be a much closer coördination between biology and geology and geography than has hitherto been admitted.

Organisms derive their support from the products of subaërial erosion of the exposed land masses. The fauna of the sea is the aquatic fringe of the fauna of the land and of the land waters which, as extensive marshes, large lakes, and epicontinental seas, were far more extensive in the geologic past than they are now. The fauna of the sea is supported by materials washed from the land, the sea itself being practically sterile.

Life is most abundant on the land in the moister regions of the tropics where there is constantly the maximum of water vapor in the air, and in the sea in the cold water of the polar regions where there is the most gas in solution in the water. Life is most varied in the tropics where physical and chemical conditions, both terrestrial and marine, are the most varied. Life occurs in greatest amount between latitudes 30° and 60° North where there is the maximum of erosion of the land surfaces and the maximum of material delivered to the seas.

Life may be defined as the ability of certain aggregations of complex carbon compounds to maintain themselves and to increase in bulk indefinitely. Naturally this increase must take place in such a way as to enable it to continue to the best advantage.

Living matter requires a constant supply of new materials, of water, and of certain gases, and a suitable temperature.

Temperature chiefly affects organisms through its effect on the vital

problem of securing and conserving water. In their relations to temperature, as in their structure, the sexual products of all animals more nearly resemble the protozoans than the animals from which they are derived.

Light is as essential for animals as it is for plants, and luminescence in marine organisms is a physiological necessity in supplying the animals of the deep sea with the type of light which is necessary for their existence. The superabundance of light, especially of the longer wave lengths, on the land and in shallow water has necessitated the development in terrestrial and shallow water creatures of superficial pigmentation for protection, which secondarily has developed into complex color patterns. Strong light has also led to the development of visual eyes which, when they occur, are the chief factor in the control of the animal possessing them to which all other factors are more or less subordinated. Sound waves in air have led to the development of ears, which in the control of the reactions of the animals possessing them are second in importance to the eyes, and also to the development of various sound producing mechanisms or habits.

The development of all animals is reducible to a simple geometrical plan. All animals begin as a single cell which divides into two, each of these dividing in the same way, and this process continuing indefinitely. All animals of every type agree in this. The cells as they divide may completely separate, giving rise to the so-called protozoan type; they may adhere in a subregular mass, giving rise to the sponge type; or they may divide regularly in such a way as to form a hollow sphere which, collapsing, forms a cup with an outer and an inner layer of cells. Further development of this cup, known as a gastrula, would naturally give rise to a radially symmetrical animal.

The three fundamental types of animal life are therefore the protozoan, in which the individuals are composed of isolated cells; the sponge, in which the cells are agglutinated in a subregular mass; and the radially symmetrical, in which the germ cell develops geometrically into a radially symmetrical adult.

Presumably each of these three types developed simultaneously; if any one preceded the others it would probably be the sponge, from which the protozoans were derived by a complete separation of the cells, and the others by a geometrical arrangement of the cells as they divided.

All of the so-called higher animals (worms, insects, crustaceans,

vertebrates, etc.) are bilaterally symmetrical with a head end at which are the mouth, the chief sense organs, and the central nervous system. But all of these pass through a gastrula or cup-shaped stage which is the last stage they have in common and is therefore the stage from which they radiate into their several diverse forms. Since all bilaterally symmetrical animals pass through a stage of radial symmetry comparable to the adult form of radially symmetrical types, it is a logical inference that they all are derived through radially symmetrical ancestry by a change from symmetrical to asymmetrical development.

This conception of the genesis of the numerous animal types brings their development into harmony with physical conditions surrounding them; furthermore each animal type is allocated in a definite place so that there are no exceptions or so-called aberrant forms. Also no time element is involved; the appearance of all the major animal types may well have been simultaneous.

Animal perfection is to be judged from the perfection of the adaptation to the environment, not from preconceived structural standards. All existing animals are of the same relative degree of perfection.

Life probably arose in or on the surface of the soil of marshes in non-saline, or at most slightly saline, water, thence spreading out over the land and down into the water. The correspondence between sea and land life is so close as to indicate that they are inseparable parts of a single whole.

All animals vary in every possible direction from the typical form, but only such of the young survive as are able to meet the ecological conditions under which the parents live. So-called aberrations, abnormalities, and deformities are really only extreme variants which have managed to survive. Any one of these may give rise to a new species, genus, or higher group if it succeeds in reaching a situation in which it is capable of meeting the economic conditions.

Variations may be induced by external factors; but usually in nature they arise from differences in the correlation of the components of the complex of characters composing the individuals which have no evident relation to external conditions.

With changing conditions an animal type may change its form by simply substituting for the previously normal form that variant best suited to meet the new conditions.

The reason for the extinction of the great reptiles and other comparable creatures of the past was that, being large, they were relatively

few in numbers, and the variants therefore were so very few as to be in effect isolated abnormalities; with variants so very few as to be merely wholly isolated instances of departure from the usual type, the type becomes stabilized and inflexible and incapable of meeting new conditions by a migration of the average along one of the radii of variation.

Development along any line, such as great increase in size or a high degree of specialization, that decreases the number of individuals reduces the number of variants proportionately. Thus it is that the fossil record shows a continuation of the various animal lines always from the smaller and more generalized types, those which increase in size and in specialization coming to a sudden and abrupt end.

The germ cells and the protoplasm of the "decadent" elephants, rhinoceros, giraffes, bison and similar creatures are certainly no older than those of the virile and adaptable rats and mice. The difference between them is not one of relative type virility, but of relative size and consequently number of individuals. Abundance of individuals in any animal types means great plasticity through the abundance of variants produced, any one of which may, if conditions change, supplant the prevailing form in any given region.

There is no reason to suppose that the formation of new animal types is not taking place at the present day as actively as at any time in the past. The three regions of the world which at present seem to be the most active centers in the production of new forms are (1) central Asia from the Himalayas northward, (2) western South America, and (3) New Guinea. In these three regions there is the maximum diversity of conditions combined with great geological activity.

The central Asian region is, and apparently long has been, the most important center of animal distribution. From this area there has been easy and uninterrupted ingress into Europe and Africa, and also into North America. But only such Asiatic types have reached South America as have been able to pass through rough forested mountain country. The ingress into the Australian region has been still more difficult, and here only those mammalian types have been able to survive (marsupials and small rodents) which are best suited to meet adverse conditions. In the past there was a direct land connection between South America, New Zealand, and Australia as is evidenced by a striking correspondence in the fauna of the regions. This must have been over the Antarctic continent. The large hoofed animals and comparable creatures of Asiatic origin having been unable to pass

into South America, there were developed there in the past numerous corresponding creatures having their origin in generalized types which had been able to invade that continent. In Australia conditions were such as to prevent the development of large herbivorous mammals and their correlated predators from any but marsupial stock. The southern part of the mountain area in North America appears today to be an active center in the formation of new animal types among the smaller creatures. In the past this mountain region in western North America seems to have been as important as the corresponding region in South America.